



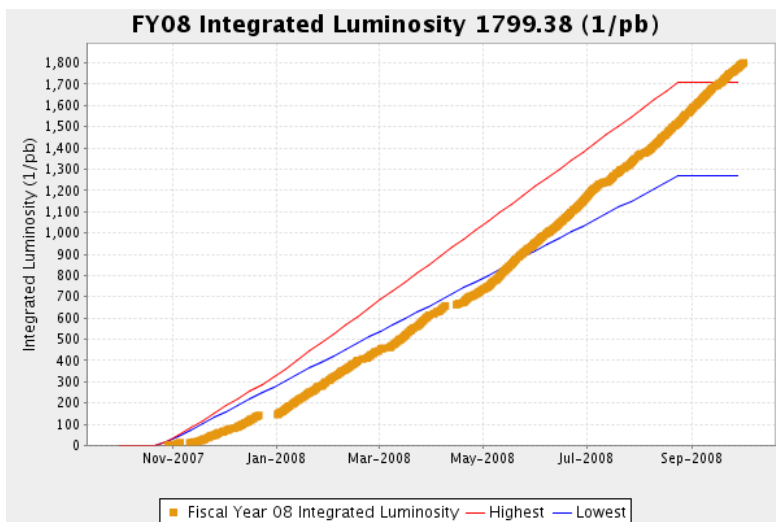
Tevatron Physics

Fermilab Physics Advisory Committee – 3 November 2008

Marco Verzocchi
Fermilab / PPD

- **Status and performance: accelerator and experiments**
- **Tevatron legacy measurements: top and W mass**
- **Indirect constraints on the Higgs mass**
- **Higgs searches and related SM measurements**
- **New b-physics and spectroscopy results**
- **New physics**

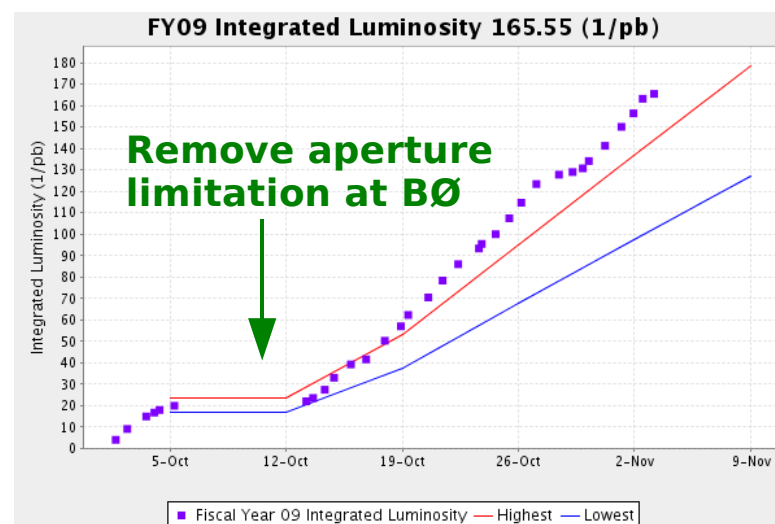
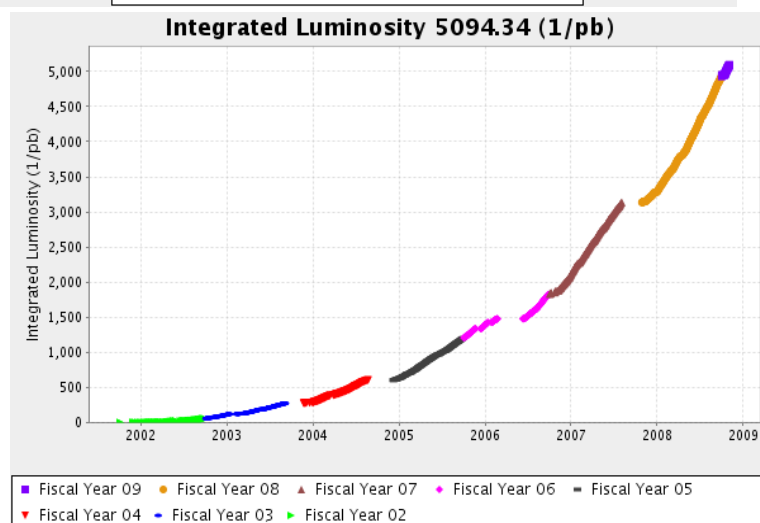
Tevatron Performance



Surpassed target integrated luminosity for FY08:

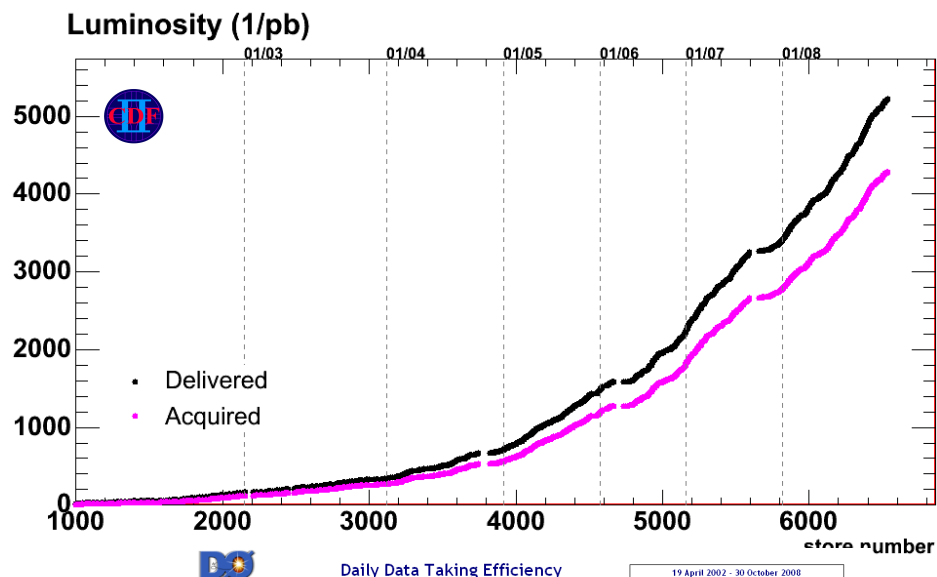
- increased stacking rate
- shorter turnaround time
- stability of machine (106 hours/week)
- improved luminosity lifetime

FY09 started well (1 week shutdown for work on powerlines to Fermilab)



More accelerator performance plots in the backup material

CDF and DØ Performance



**CDF: 5.23 fb⁻¹ delivered
4.30 fb⁻¹ recorded**

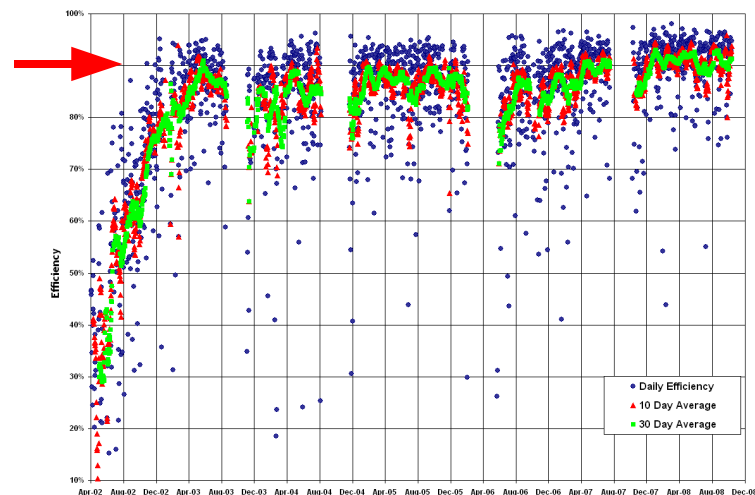
**DØ: 5.20 fb⁻¹ delivered
4.54 fb⁻¹ recorded**

**Following up quickly with
reconstruction, analysis and
publication of results**

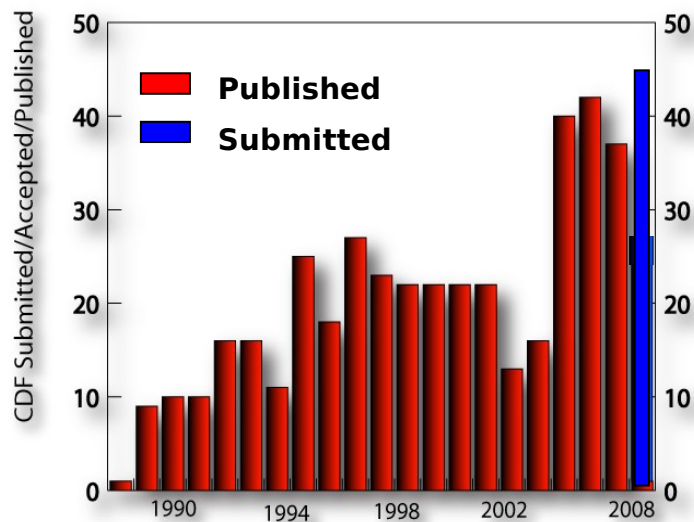
**Presented analyses with 3 fb⁻¹ at
ICHEP this past summer**

**Analyses with over 4fb⁻¹ of data
to be presented at Winter 09
conferences**

90%



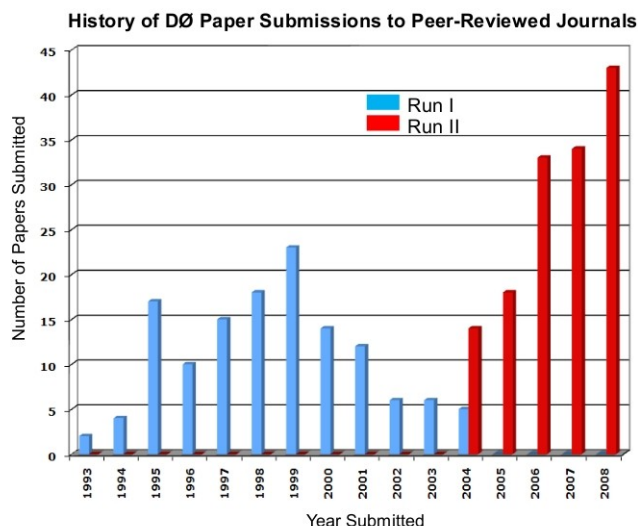
CDF and DØ Physics Results



2008 is already a record year for both experiments

**5 plenary presentations at ICHEP
40 parallel talks**

**Both experiments are still attractive
to new students/postdocs**

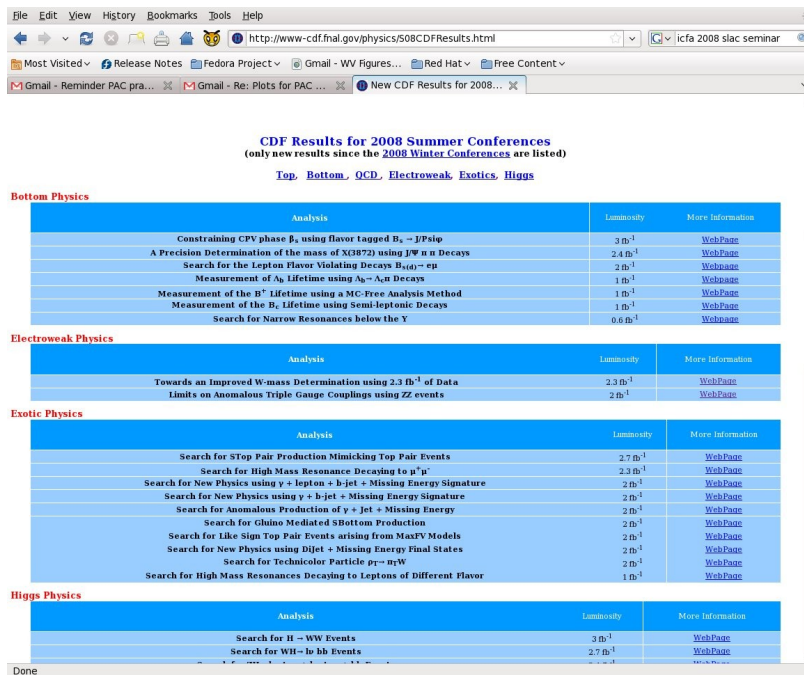


**80 PhD theses defended in 2007, 40
so far in 2008**

**Example: DØ - 22 new PhD students +
8 postdocs since January**

Too many results for 20 minutes....

Example: CDF web pages with new results for Summer 2008:
over 50 new results (similarly for DØ)



CDF Results for 2008 Summer Conferences
(only new results since the 2008 Winter Conferences are listed)

[Top](#), [Bottom](#), [QCD](#), [Electroweak](#), [Exotics](#), [Higgs](#)

Analysis	Luminosity	More Information
Constraining CPV phase β_s using flavor tagged $B_s \rightarrow J/\psi \pi^0$	3 fb^{-1}	WebPage
A Precision Determination of the mass of $X(3872)$ using $J/\psi \pi^0 \pi^0$ Decays	2.4 fb^{-1}	WebPage
Search for the Lepton Flavor Violating Decays $B_{s(d)} \rightarrow e \mu$	2 fb^{-1}	WebPage
Measurement of λ_b Lifetime using $b_b \rightarrow \Lambda_b^0$ Decays	1 fb^{-1}	WebPage
Measurement of the B^0 Lifetime using a MC-Free Analysis Method	1 fb^{-1}	WebPage
Measurement of the B_s Lifetime using Semi-leptonic Decays	1 fb^{-1}	WebPage
Search for Narrow Resonances below the Υ	0.6 fb^{-1}	WebPage

Electroweak Physics

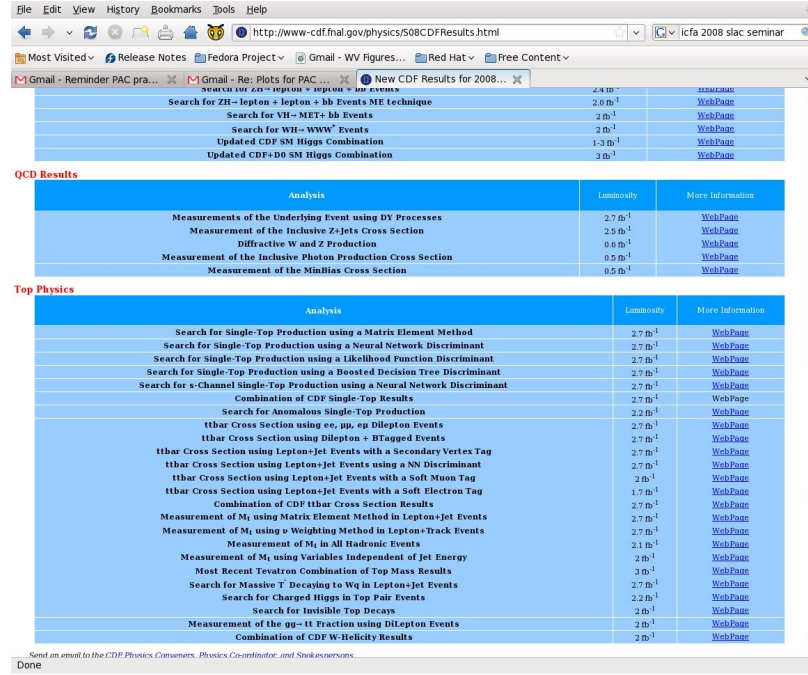
Analysis	Luminosity	More Information
Towards an Improved W-mass Determination using 2.3 fb^{-1} of Data	2.3 fb^{-1}	WebPage
Limits on Anomalous Triple Gauge Couplings using ZZ events	2 fb^{-1}	WebPage

Exotic Physics

Analysis	Luminosity	More Information
Search for S-Top Pair Production Mimicking Top Pair Events	2.7 fb^{-1}	WebPage
Search for High Mass Resonances Decaying to $\mu^+\mu^-$	2.3 fb^{-1}	WebPage
Search for New Physics using $\gamma + \text{lepton} + b\text{-jet} + \text{Missing Energy Signature}$	2 fb^{-1}	WebPage
Search for New Physics using $\gamma + b\text{-jet} + \text{Missing Energy Signature}$	2 fb^{-1}	WebPage
Search for Anomalous Production of $\gamma + \text{jet} + \text{Missing Energy}$	2 fb^{-1}	WebPage
Search for Gluino Mediated S-Top Production	2 fb^{-1}	WebPage
Search for Like Sign Top Pair Events arising from MassIV Models	2 fb^{-1}	WebPage
Search for New Physics using Dijet + Missing Energy Final States	2 fb^{-1}	WebPage
Search for Technicolor Particle $p_1 \rightarrow \pi \gamma W$	2 fb^{-1}	WebPage
Search for High Mass Resonances Decaying to Leptons of Different Flavor	1 fb^{-1}	WebPage

Higgs Physics

Analysis	Luminosity	More Information
Search for H - WW Events	3 fb^{-1}	WebPage
Search for WH - $b\bar{b}$ Events	2.7 fb^{-1}	WebPage



CDF Results for 2008 Summer Conferences
(only new results since the 2008 Winter Conferences are listed)

[Top](#), [Bottom](#), [QCD](#), [Electroweak](#), [Exotics](#), [Higgs](#)

Analysis	Luminosity	More Information
Search for $2\text{-jet} + \text{lepton} + b\bar{b}$ Events	2.9 fb^{-1}	WebPage
Search for $2\text{-jet} + \text{lepton} + b\bar{b}$ Events	2 fb^{-1}	WebPage
Search for WH - WW Events	2 fb^{-1}	WebPage
Updated CDF SM Higgs Combination	1.3 fb^{-1}	WebPage
Updated CDF+DØ SM Higgs Combination	3 fb^{-1}	WebPage

QCD Results

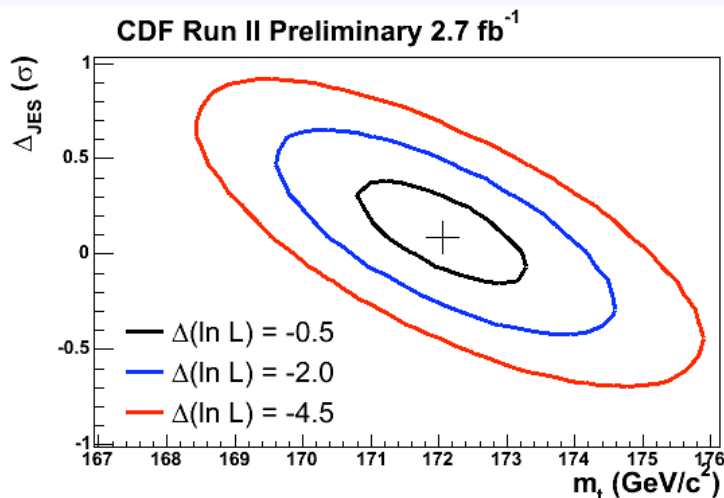
Analysis	Luminosity	More Information
Measurements of the Underlying Event using DY Processes	2.7 fb^{-1}	WebPage
Measurement of the Inclusive 2-jets Cross Section	2.5 fb^{-1}	WebPage
Diffraction W and Z Production	0.6 fb^{-1}	WebPage
Measurement of the Inclusive Photon Production Cross Section	0.5 fb^{-1}	WebPage
Measurement of the Minibias Cross Section	0.5 fb^{-1}	WebPage

Top Physics

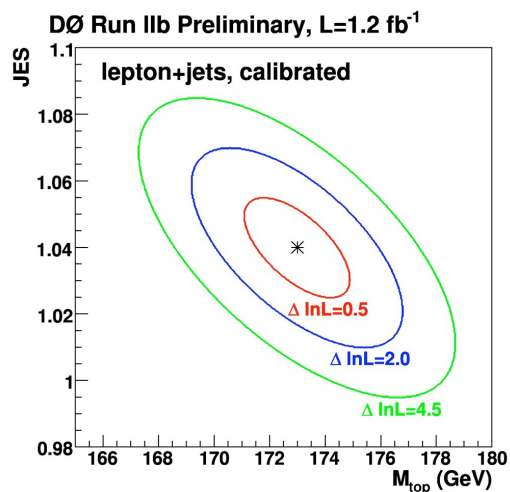
Analysis	Luminosity	More Information
Search for Single-Top Production using a Matrix Element Method	2.7 fb^{-1}	WebPage
Search for Single-Top Production using a Neural Network Discriminant	2.7 fb^{-1}	WebPage
Search for Single-Top Production using a Likelihood Function Discriminant	2.7 fb^{-1}	WebPage
Search for Single-Top Production using a Boosted Decision Tree Discriminant	2.7 fb^{-1}	WebPage
Search for s-Channel Single-Top Production using a Neural Network Discriminant	2.7 fb^{-1}	WebPage
Combination of CDF Single-Top Results	2.7 fb^{-1}	WebPage
Search for Anomalous Single-Top Production	2.2 fb^{-1}	WebPage
tbar Cross Section using $e^+e^- \mu^+\mu^-$ Dilepton Events	2.7 fb^{-1}	WebPage
tbar Cross Section using Dilepton + B-Tagged Events	2.7 fb^{-1}	WebPage
tbar Cross Section using Lepton+jet Events with a Secondary Vertex Tag	2.7 fb^{-1}	WebPage
tbar Cross Section using Lepton+jet Events with a NN Discriminant	2.7 fb^{-1}	WebPage
tbar Cross Section using Lepton+jet Events with a Soft Muon Tag	2 fb^{-1}	WebPage
tbar Cross Section using Lepton+jet Events with a Soft Electron Tag	1.7 fb^{-1}	WebPage
Combination of CDF tbar Cross Section Results	2.7 fb^{-1}	WebPage
Measurement of M_t using Matrix Element Method in Lepton+jet Events	2.7 fb^{-1}	WebPage
Measurement of M_t using $\mu^+\mu^-$ Weighting Method in Lepton+Track Events	2.7 fb^{-1}	WebPage
Measurement of M_t in All Hadronic Events	2.1 fb^{-1}	WebPage
Measurement of M_t using Variables Independent of Jet Energy	2 fb^{-1}	WebPage
Most Recent Tevatron Combination of Top Mass Results	3 fb^{-1}	WebPage
Search for Massive T' Decaying to Wq in Lepton+jet Events	2.7 fb^{-1}	WebPage
Search for Charged Higgs in Top Pair Events	2.2 fb^{-1}	WebPage
Search for Invisible Top Decays	2 fb^{-1}	WebPage
Measurement of the $gg \rightarrow t\bar{t}$ Fraction using Dilepton Events	2 fb^{-1}	WebPage
Combination of CDF W-Helicity Results	2 fb^{-1}	WebPage

Will focus on a subset of new physics results since last PAC meeting

Constraining $m_H : m_{top}$

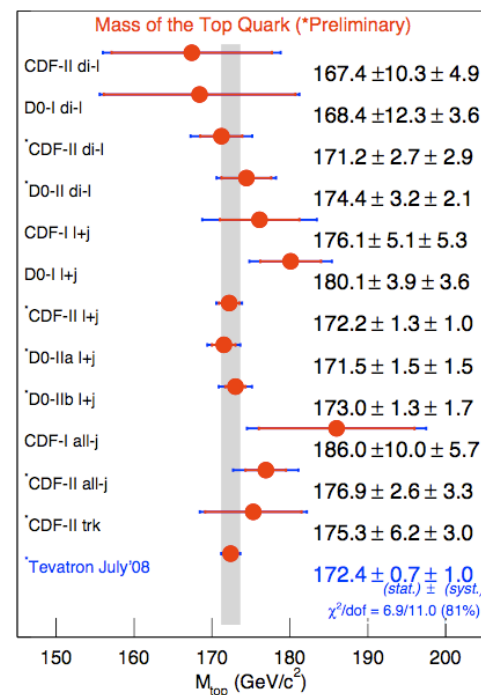


CDF: $m_t = 172.2 \pm 1.0 \pm 1.3$ GeV



DØ: $m_t = 172.2 \pm 1.0 \pm 1.4$ GeV

Most relevant channels now 2.7 fb⁻¹

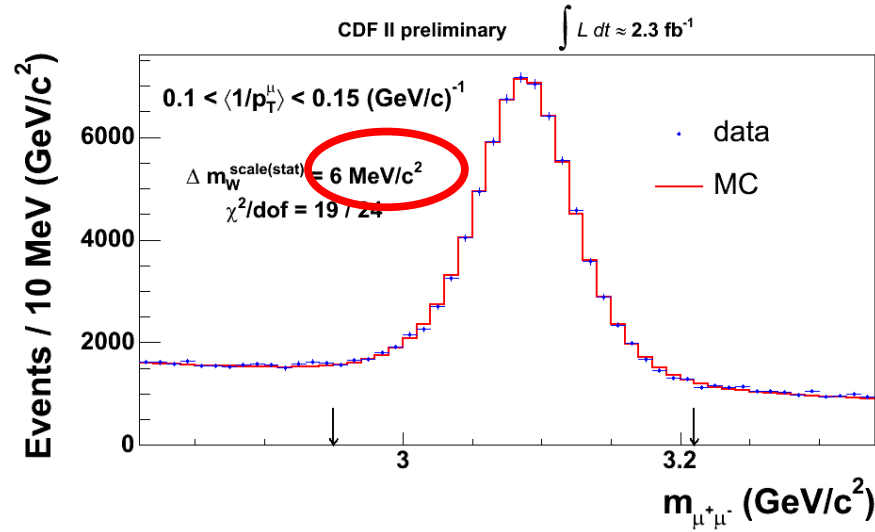


World average top quark mass (ICHEP 08)

$m_t = 172.4 \pm 0.7 \pm 1.0$ GeV

0.7 % precision

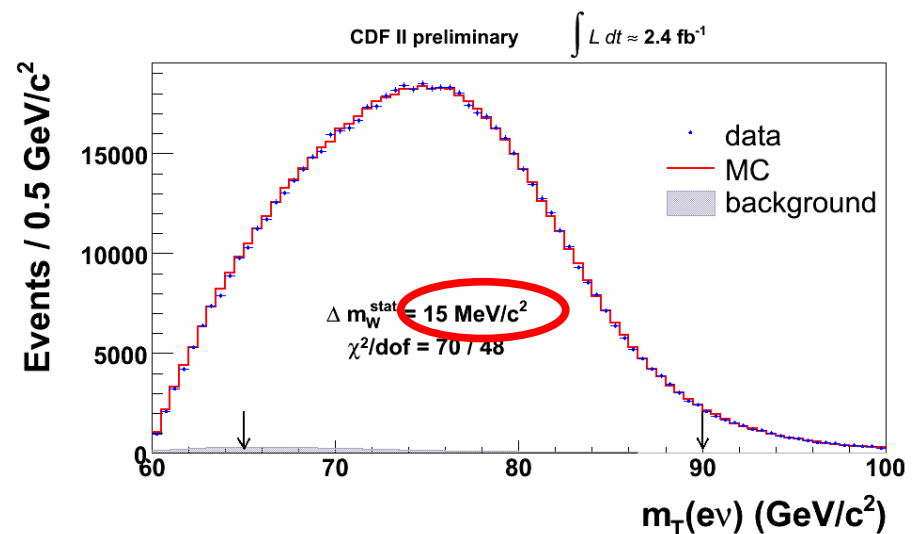
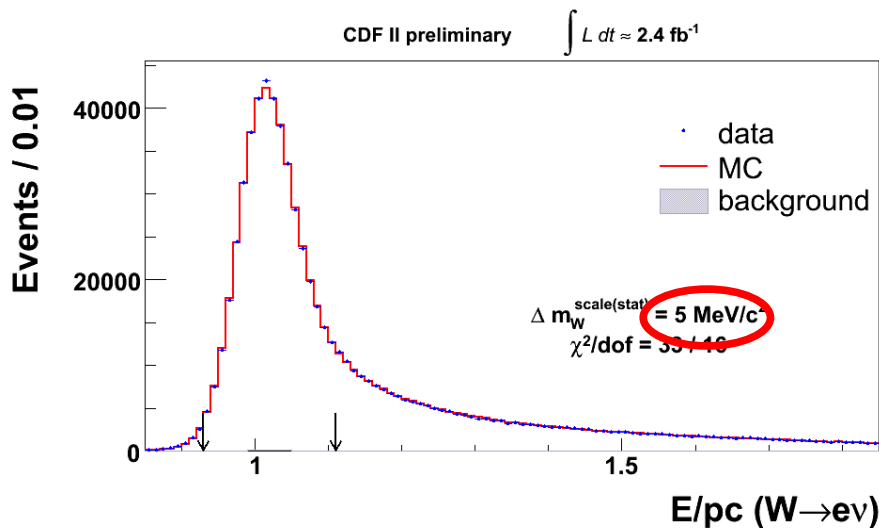
Constraining $m_H : m_W$



**Current m_W world average:
precision 25 MeV (CDF best single
experiment result)**

**CDF: working on 2.4 fb^{-1} analysis
Expect to have measurement with
precision equivalent to world
average**

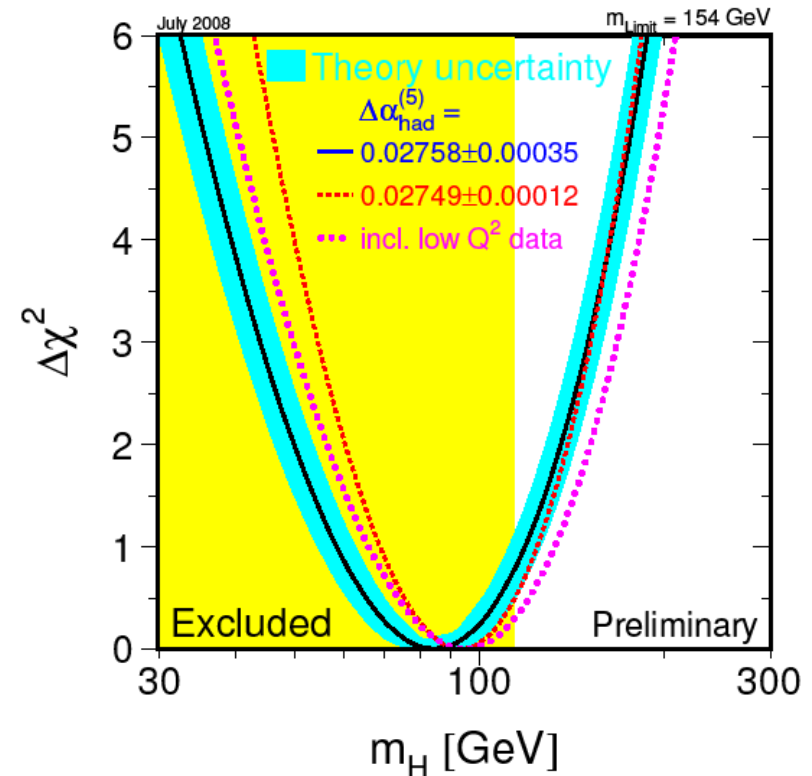
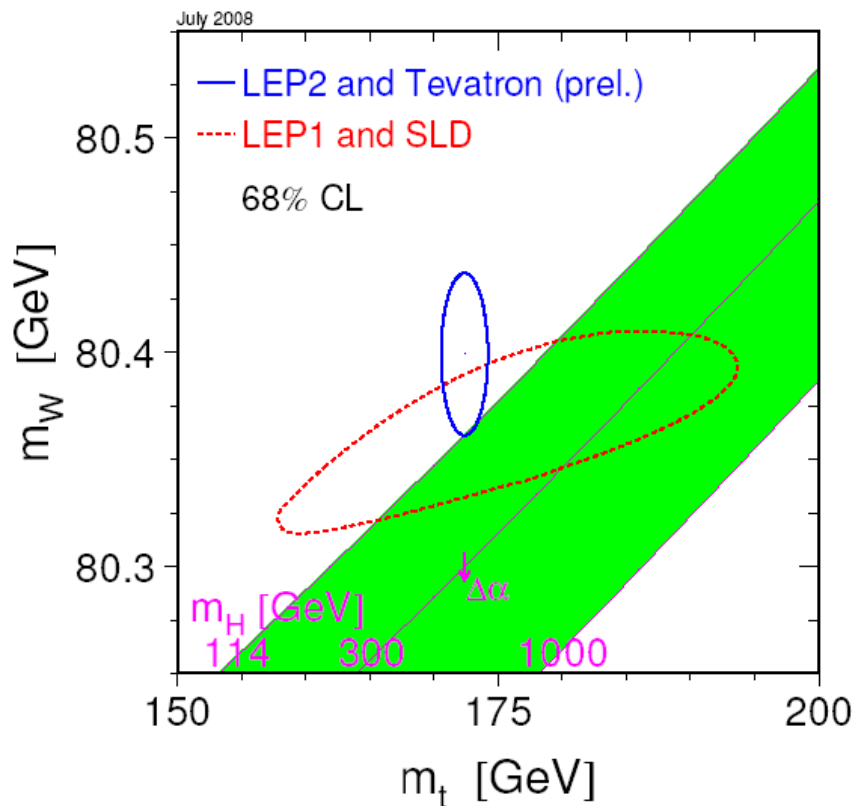
DØ: publish 1 fb^{-1} analysis soon



Constraining m_H : Electroweak Fits

$$m_H = 84^{+34}_{-26} \text{ GeV}$$

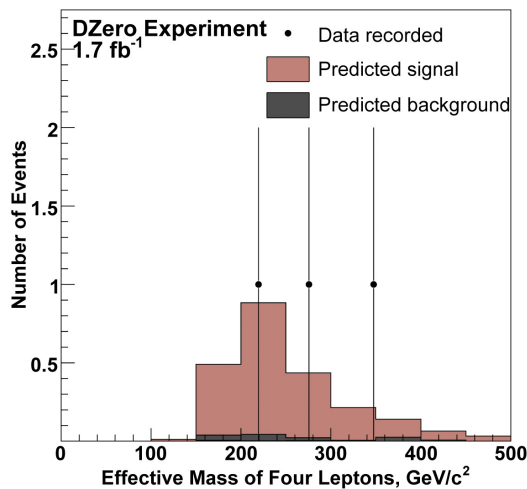
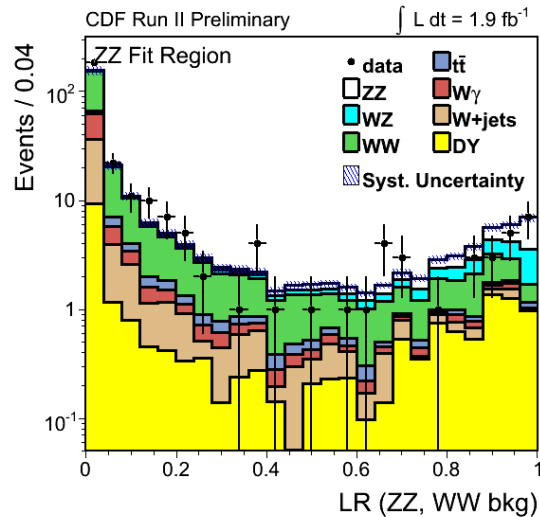
$$m_H < 154 \text{ GeV @ 95\% CL}$$



Impact of uncertainties on M_H :

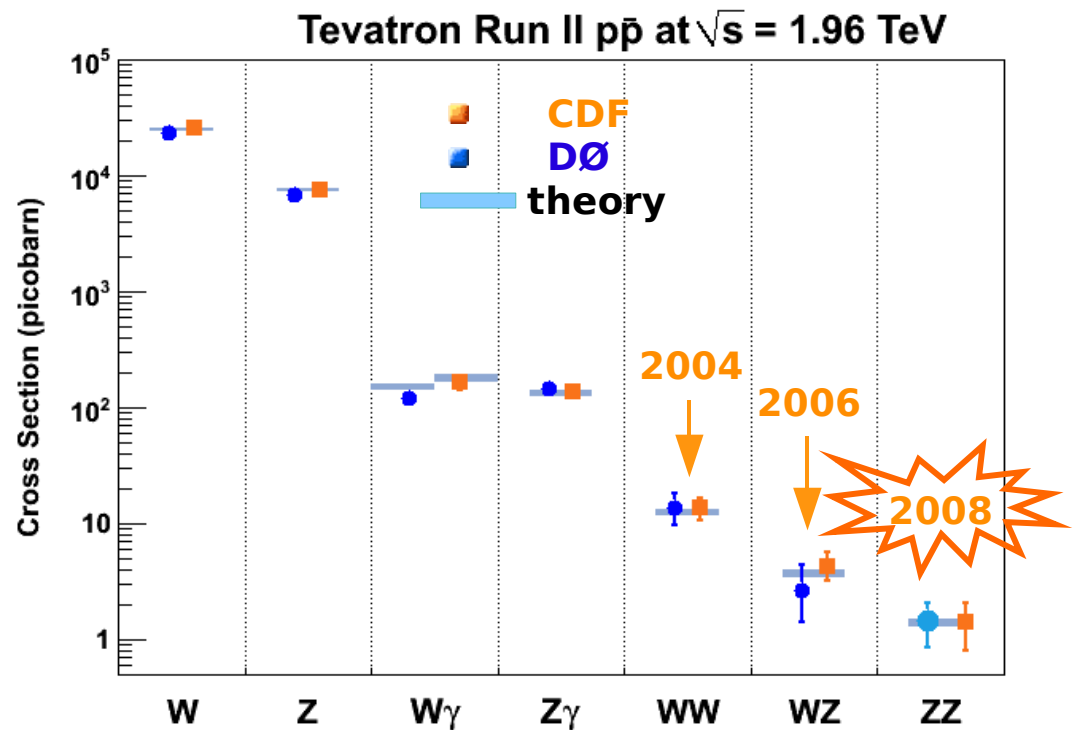
$\Delta M_t = \pm 1.2 \text{ GeV}$	$\Delta M_H = +9/-8 \text{ GeV}$
$\Delta M_W = \pm 25 \text{ MeV}$	$\Delta M_H = -13/+17 \text{ GeV}$
$\Delta\alpha_{\text{had}}^{(5)} = \pm 0.00035$	$\Delta M_H = -15/+17 \text{ GeV}$

Diboson Processes at Tevatron



Both CDF and DØ combine $ZZ \rightarrow ll\nu\nu$ and $ZZ \rightarrow ll ll$ channels to obtain 4.4σ and 5.7σ significance respectively

Cross sections measured in agreement with SM prediction of 1.4 pb



... now also with Hadronic W/Z Decays

Select sample of $q\bar{q}lv$ events in 1.1 fb^{-1} of data

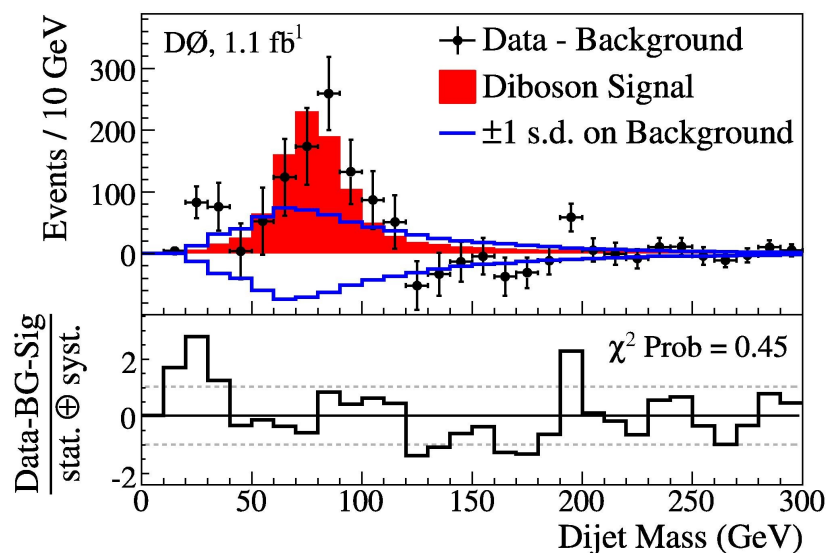
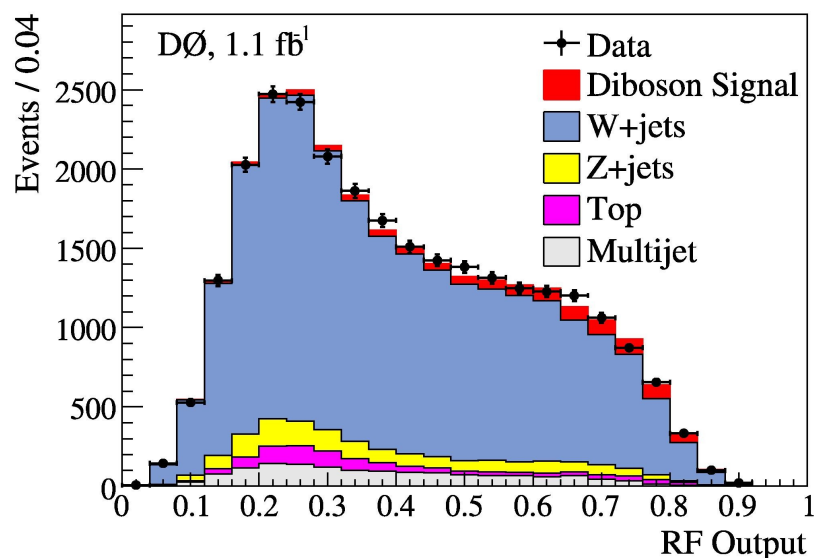
Cannot separate W and $Z \rightarrow q\bar{q}$, measure sum of two processes

Use Random Forest discriminant to separate signal (600 events) from background (27k events)

Measure $\sigma = 20.2 \pm 2.8(\text{stat}) \pm 4.9(\text{syst}) \pm 1.1(\text{lum}) \text{ pb}$ (4.4σ)

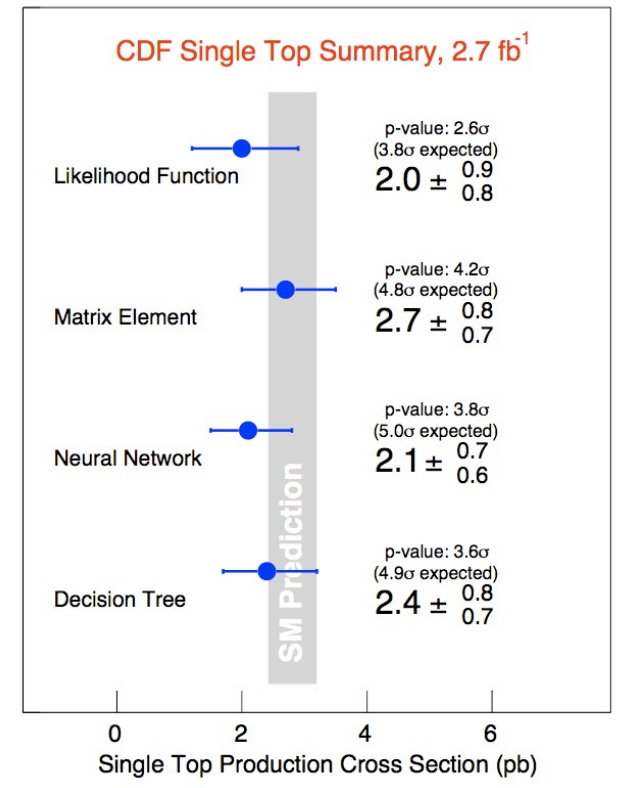
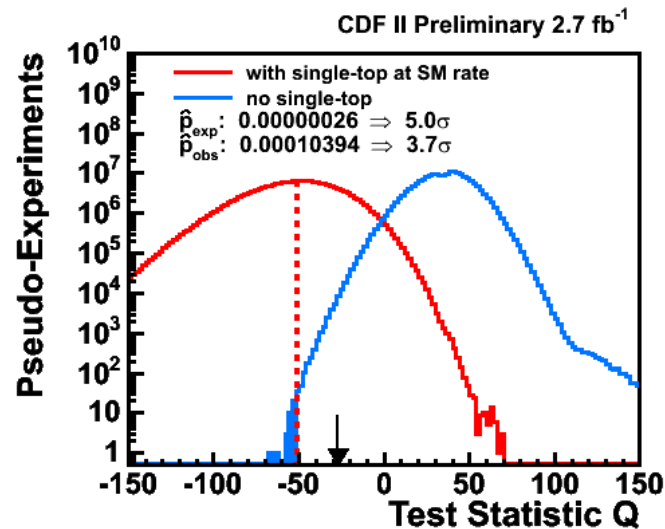
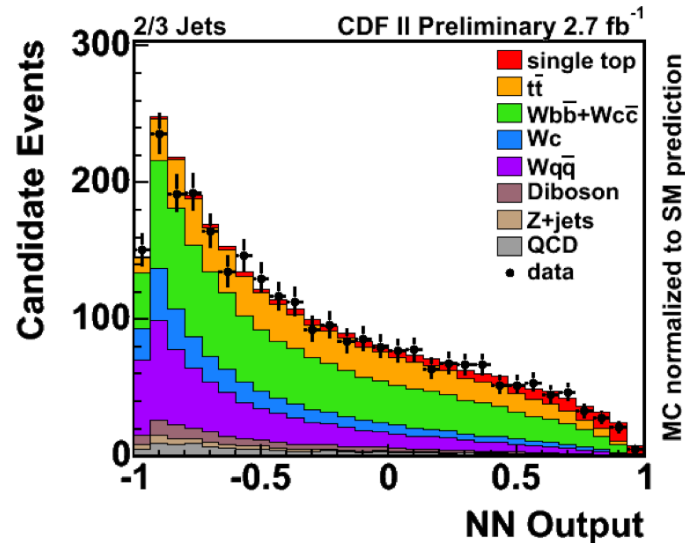
SM $\sigma = 16.1 \pm 0.9 \text{ pb}$

Main systematics: background (W+2jets) shape, jet energy scale, cross sections



With more data: observe $Z \rightarrow b\bar{b}$, separate W/Z contributions to signal

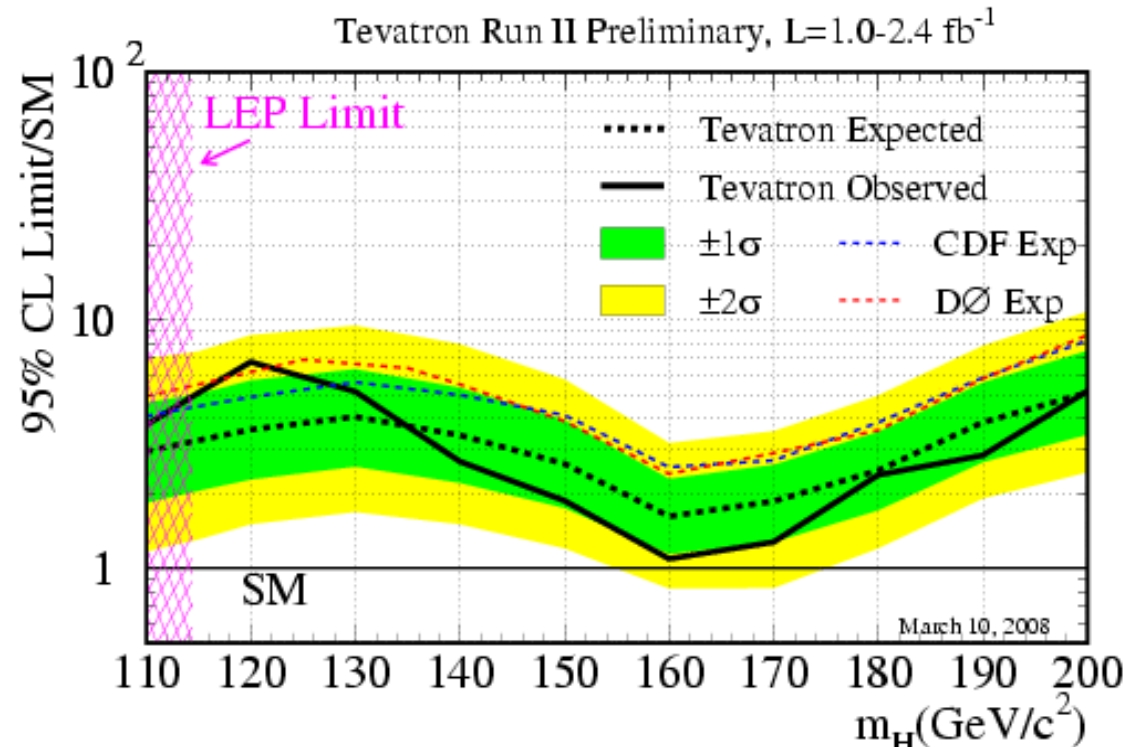
Single top Production



Both CDF and DØ now have evidence for single top production, reach 5 σ soon

Smallest cross section measured in final states containing jets

Higgs Searches (March 2008)



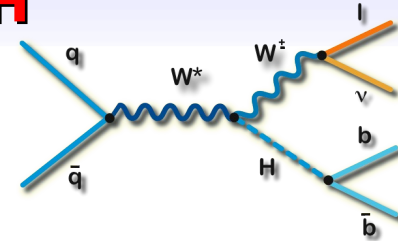
Tevatron combination limit/SM:

- **6.8 at $m_H=120 \text{ GeV}/c^2$**
- **1.1 at $m_H=160 \text{ GeV}/c^2$**

Since then: analyzed more data, improvement in the analyses, more channels added at low m_H

Higgs Searches (Low m_H)

- $WH \rightarrow l\nu bb$ (most sensitive channel at low m_H)
- Signature: high p_T lepton, MET and b jets

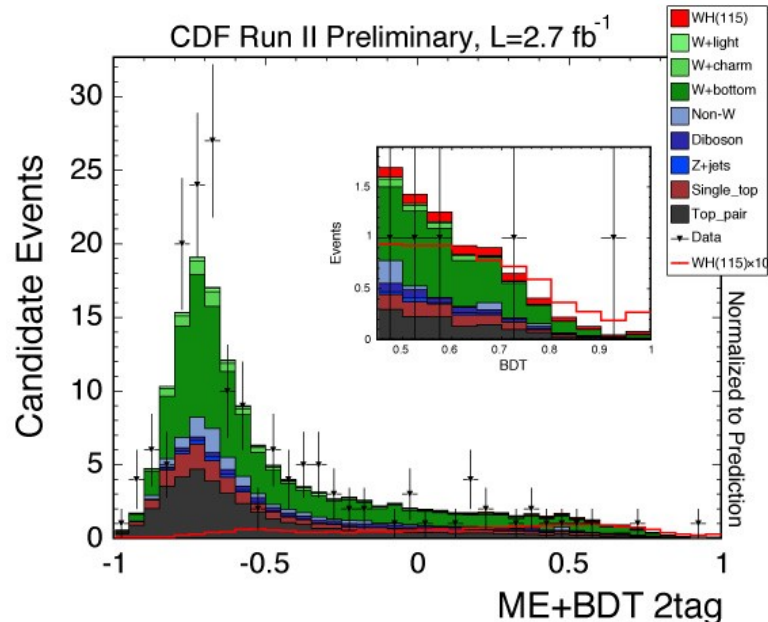


- Backgrounds: $W+bb$, $W+qq$ (mistagged), single top, Non W(QCD)
- Key issue: estimating $W+bb$ background
 - Shape from MC with normalization from data control regions

Innovations:

CDF: 20% acceptance gain from isolated tracks, ME with NN jet corrections

DØ: 20% acceptance gain from forward leptons, use 3 jet events



Results at $m_H = 115$ GeV: 95%CL Limits/SM

Analysis	Lum (fb ⁻¹)	Higgs Events	Limit (σ /SM)	
			Exp.	Obs.
CDF NN	2.7	8.3	5.8	5.0
CDF ME+BDT	2.7	7.8	5.6	5.7
DØ	1.7	7.5	8.5	9.3

Other SM Higgs Searches

- CDF and DØ are performing searches in every viable mode

- ◆ CDF/DØ: $WH \rightarrow WWW$: same sign leptons

- ◆ Adds sensitivity at high and intermediate masses
 - ◆ Also fermiophobic Higgs search

- ◆ CDF: $VH \rightarrow qqbb$: 4 jets mode

- ◆ CDF: $H \rightarrow \tau\tau$ with 2jets

- ◆ Simultaneous search for Higgs in WH/ZH, VBF and $gg \rightarrow H$ production modes
 - ◆ Interesting benchmark for LHC

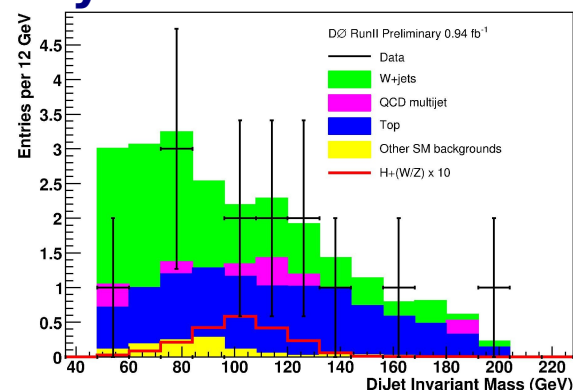
- ◆ DØ: $H \rightarrow \gamma\gamma$

- ◆ Also model independent and fermiophobic search

- ◆ DØ: $WH \rightarrow \tau\nu bb$, new mode

- ◆ Dedicated search with hadronic τ decays

- ◆ DØ: ttH , new mode

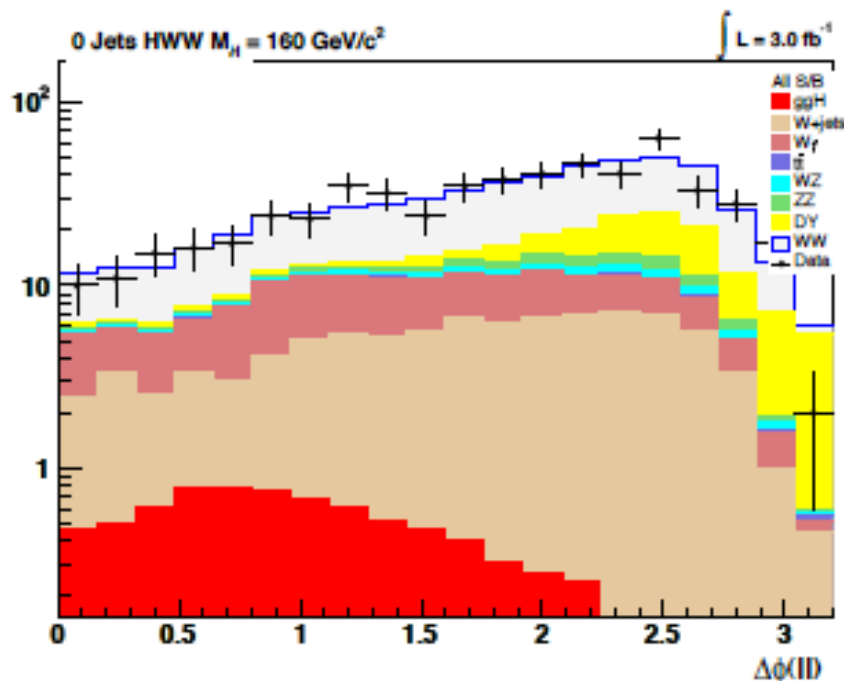
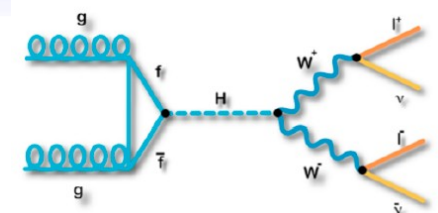


Results at $m_H = 115$ GeV or
160 GeV: 95%CL Limits/SM

Analysis	Limit (σ /SM)	
	Exp.	Obs.
CDF $WH \rightarrow WWW$	33.0	31.0
DØ $WH \rightarrow WWW$	20.0	26.0
CDF $Vh \rightarrow qqbb$	37	37
CDF $H \rightarrow \tau\tau$	25	31
DØ $WH \rightarrow \tau\nu bb$	42	35
DØ $H \rightarrow \gamma\gamma$	23	31

Higgs Searches (High m_H)

- $H \rightarrow WW \rightarrow l\nu l\nu$
- **Signature: Two high p_T leptons and MET**
 - ◆ Primary backgrounds: W pair production and top in di-lepton decay channel
 - ◆ Key issue: Maximizing lepton acceptance



Innovations:

CDF/DØ : Inclusion of acceptance from WH/ZH(CDF) and vector boson fusion

CDF : Combination of ME and NN approaches

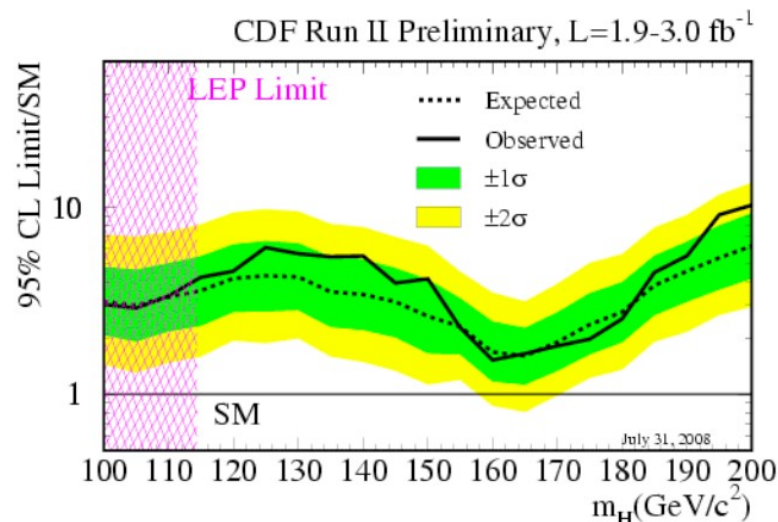
DØ: Reoptimized NN

Results at $m_H = 165 \text{ GeV}$: 95%CL Limits/SM

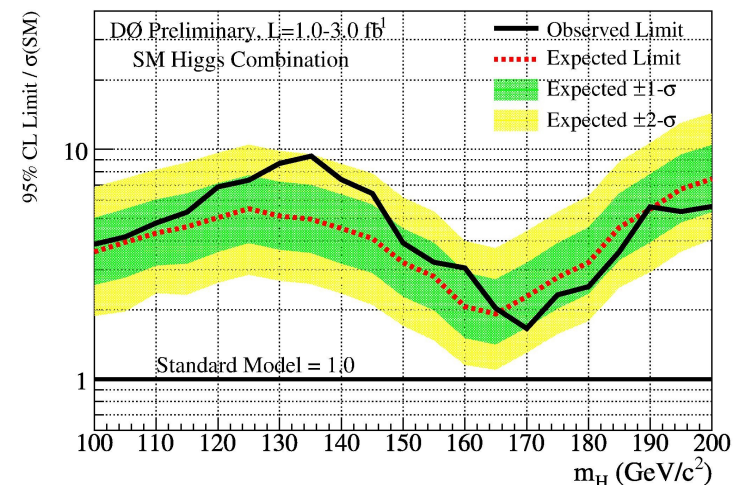
Analysis	Lum (fb^{-1})	Higgs Events	Limit (σ/SM)	
			Exp.	Obs.
CDF ME+NN	3.0	17.2	1.6	1.6
DØ NN	3.0	15.6	1.9	2.0

Single Experiment Combinations

- Limits calculating and combination
 - ◆ Using Bayesian and CLs methodologies.
 - ◆ Incorporate systematic uncertainties using pseudo-experiments (shape and rate included) (correlations taken into account between experiments)
 - ◆ Backgrounds can be constrained in the fit



ICHEP 2008 limits



- Low mass combination challenging due to ~ 70 analyses
 - Expected sensitivity of CDF/DØ combined: $< 3.0 \cdot \text{SM} @ 115 \text{ GeV}$

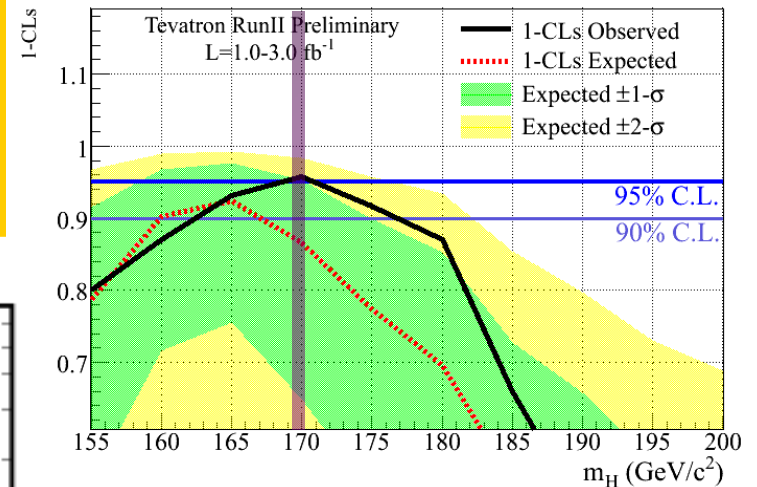
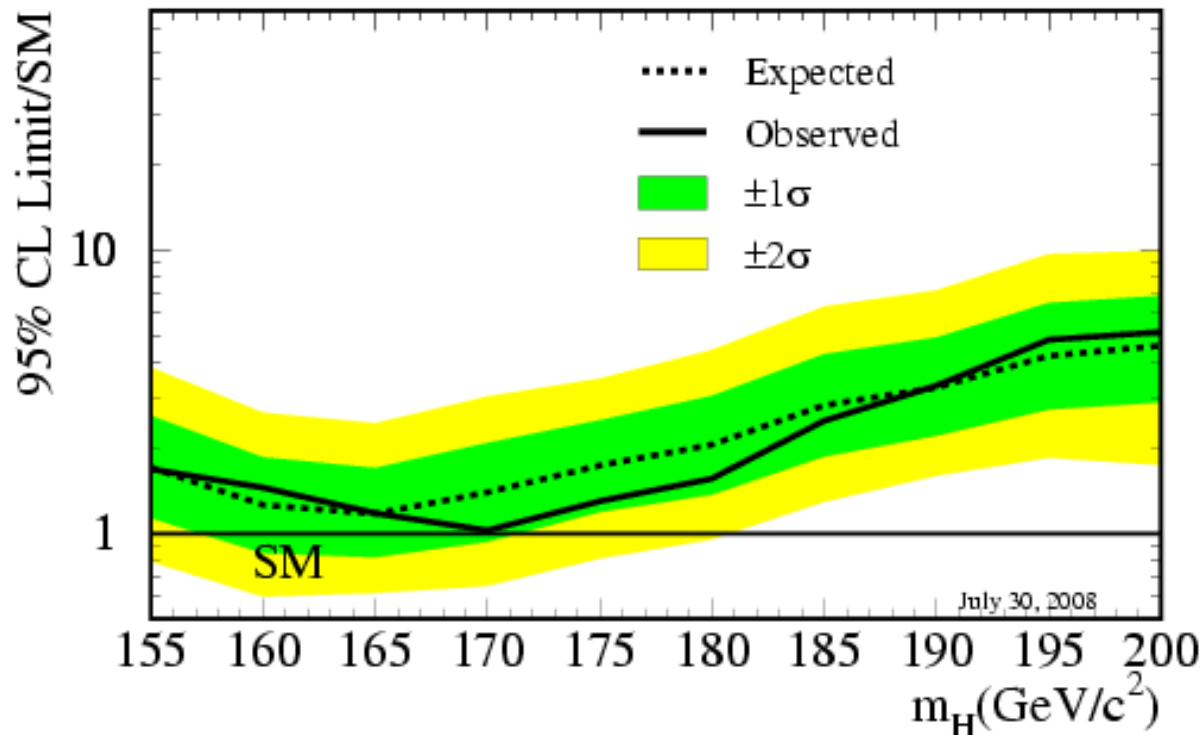
First Exclusion at High m_H

Exp. 1.2 @ 165, 1.4 @ 170 GeV

Obs. 1.0 @ 170 GeV

SM Higgs of 170 GeV excluded at 95%CL

Tevatron Run II Preliminary, $L=3 \text{ fb}^{-1}$



■ Result verified using two independent methods(Bayesian/CLs)

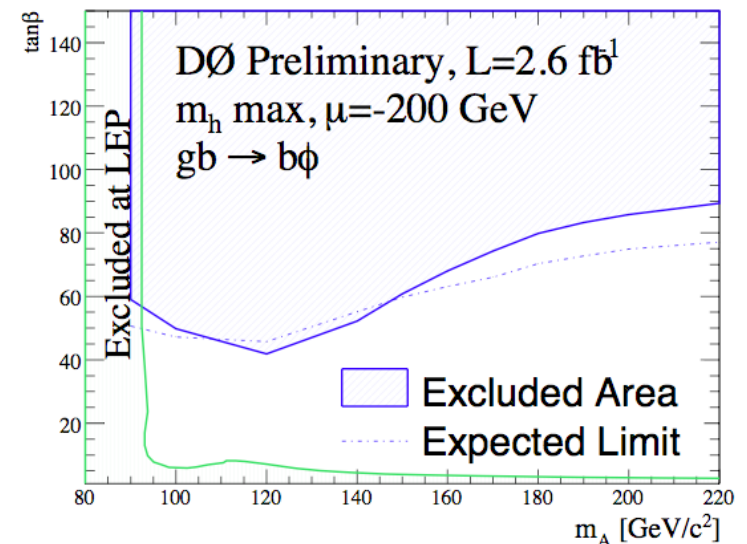
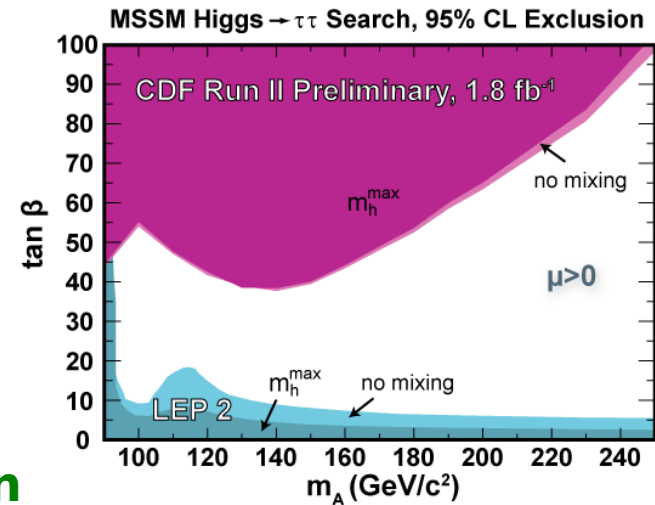
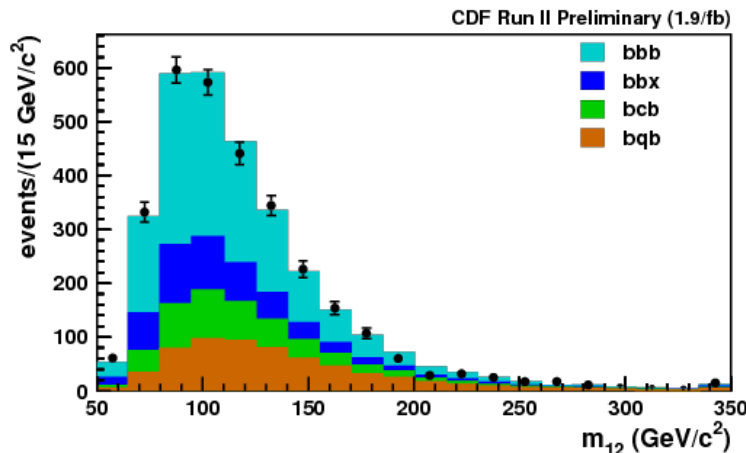
MSSM Higgs Searches

$H \rightarrow \tau\tau$ main search channel

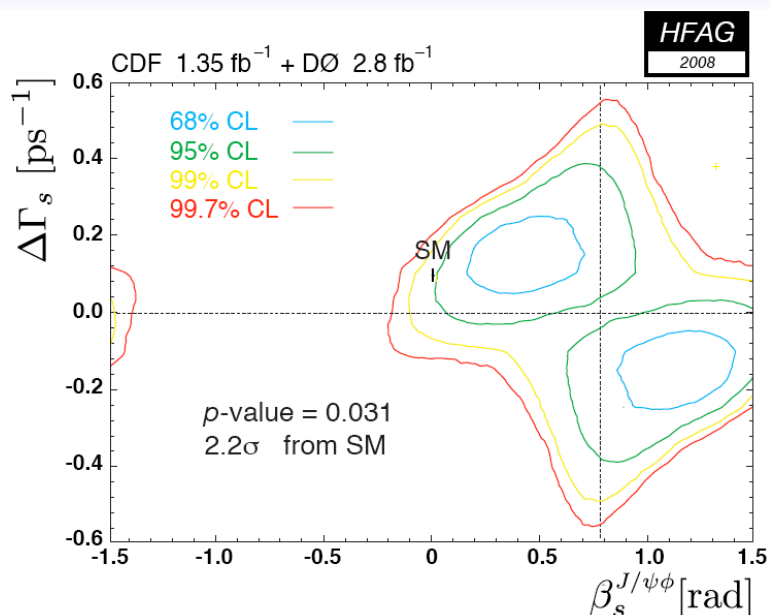
Use $b\Phi$ associated production to extend searches to Z peak region (bbb and $b\tau\tau$ final states)

First Tevatron combination available soon

Exclude high $\tan\beta$ region



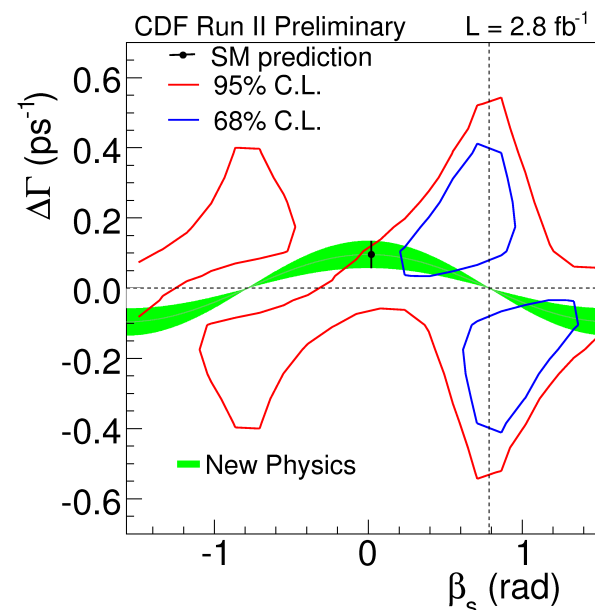
CP Violation in $J/\psi \phi$



First combination of CDF and DØ results without assumptions on strong phases: compatible at 2.2 standard deviations level with SM (p-value 0.031)

CDF: updated result with 2.8 fb^{-1}
Inconsistency with SM increased
(p-value from 0.15 to 0.08,
corresponding to 1.8 standard
deviations)

More data to come, look also in other
channels (asymmetry in semileptonic
decays)

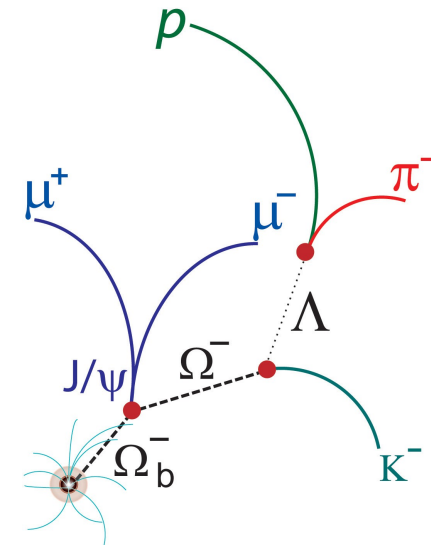
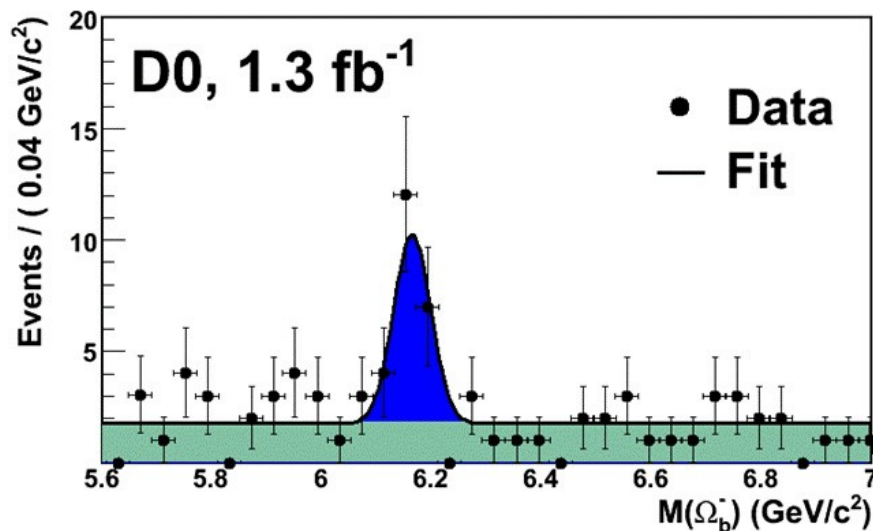


Ω_b^- Observation @ DØ

Reconstruct complicate decay chain

Ω_b^- candidates selected with multivariate technique to reduce background

Combine with J/ψ



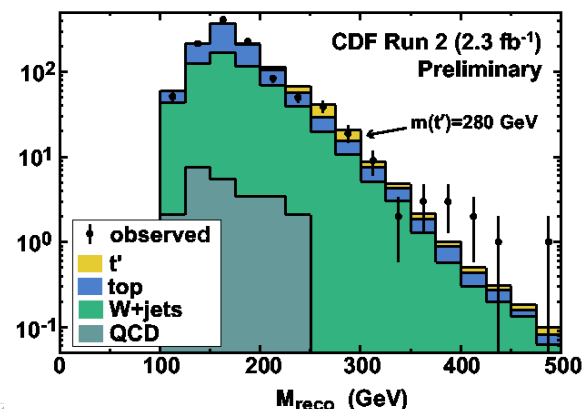
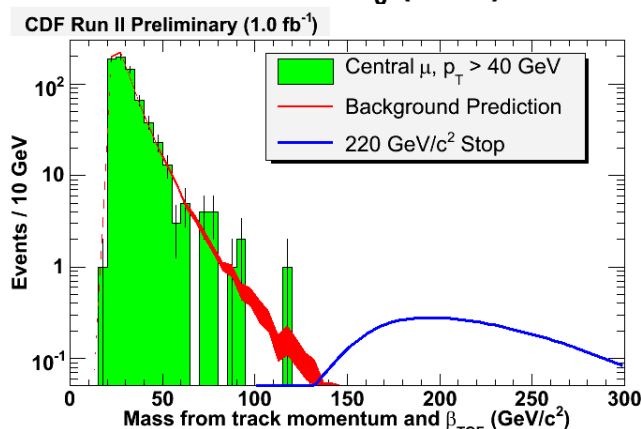
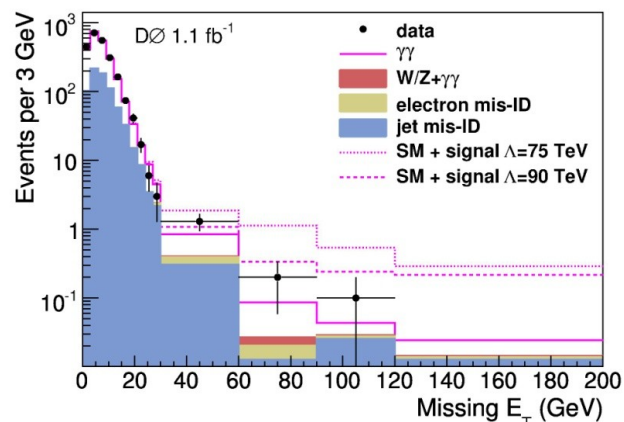
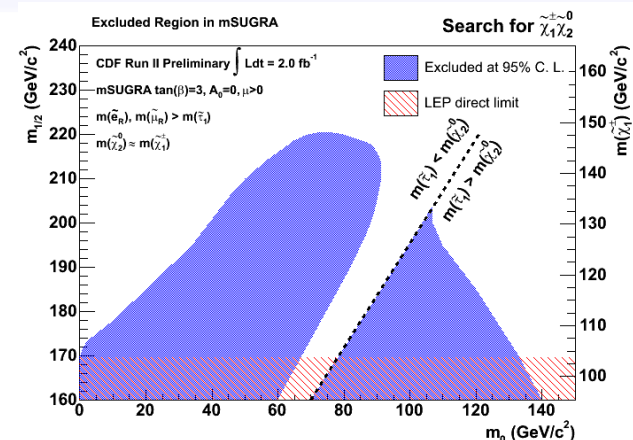
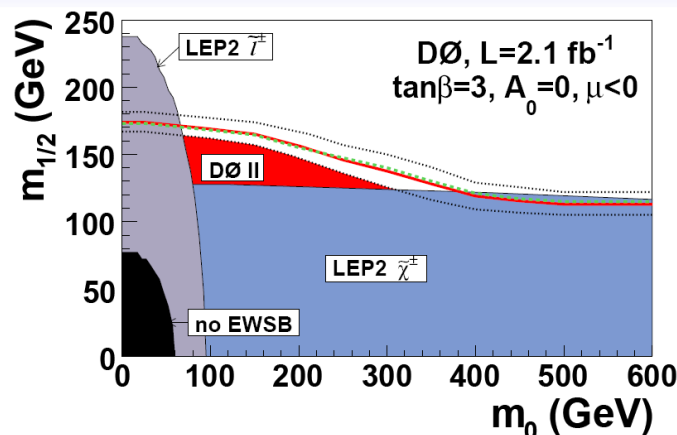
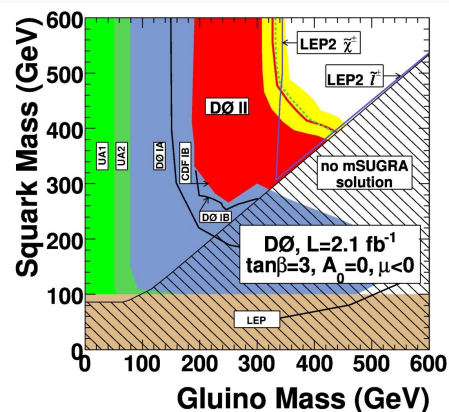
Observe $17.8 \pm 4.9 \pm 0.8$ candidates

$$m_{\Omega_b^-} = 6.156 \pm 0.010 \pm 0.013 \text{ GeV}$$

5.4 standard deviation observation

Another discovery in spectroscopy of b-hadrons

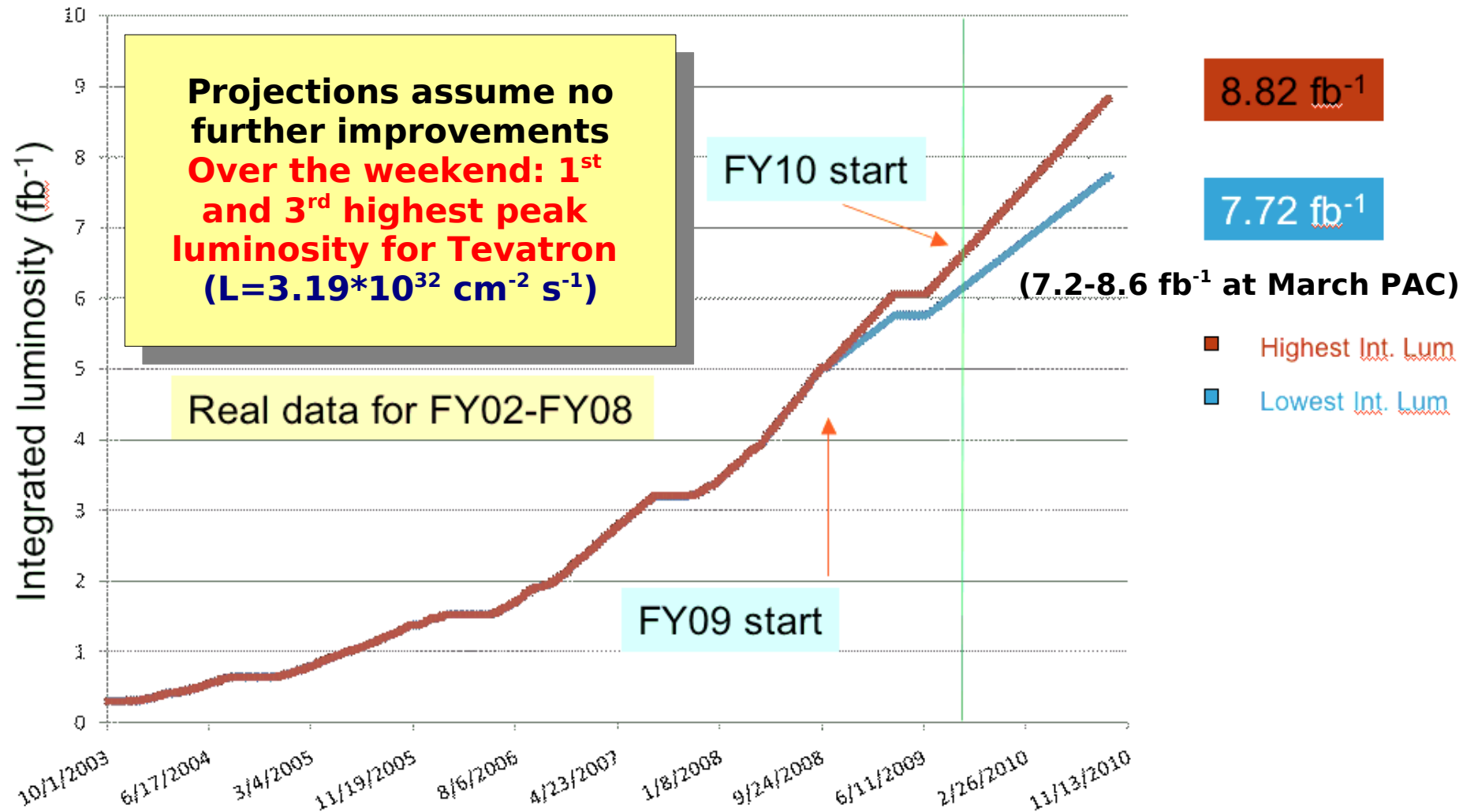
Physics beyond the SM



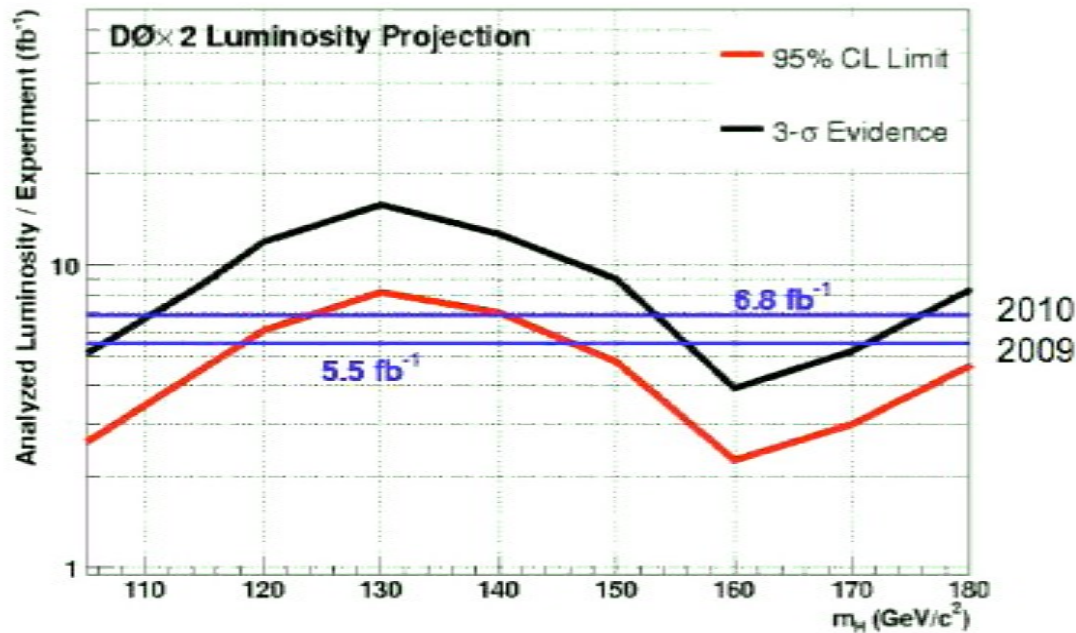
No evidence for new physics found in dedicated model driven analyses

Still room for surprises, few discrepancies at the 2-3 σ level

Future Perspectives



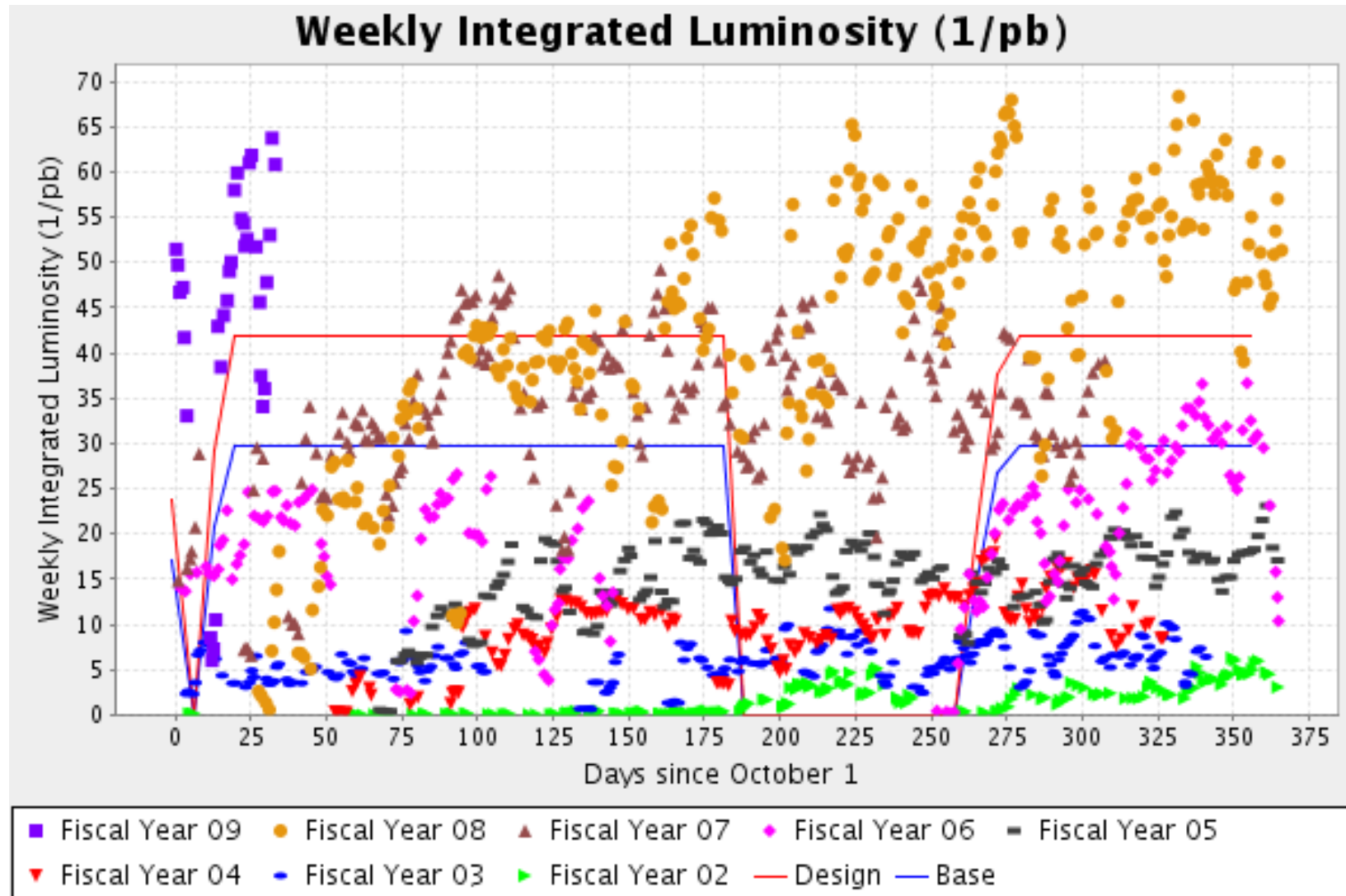
Conclusions



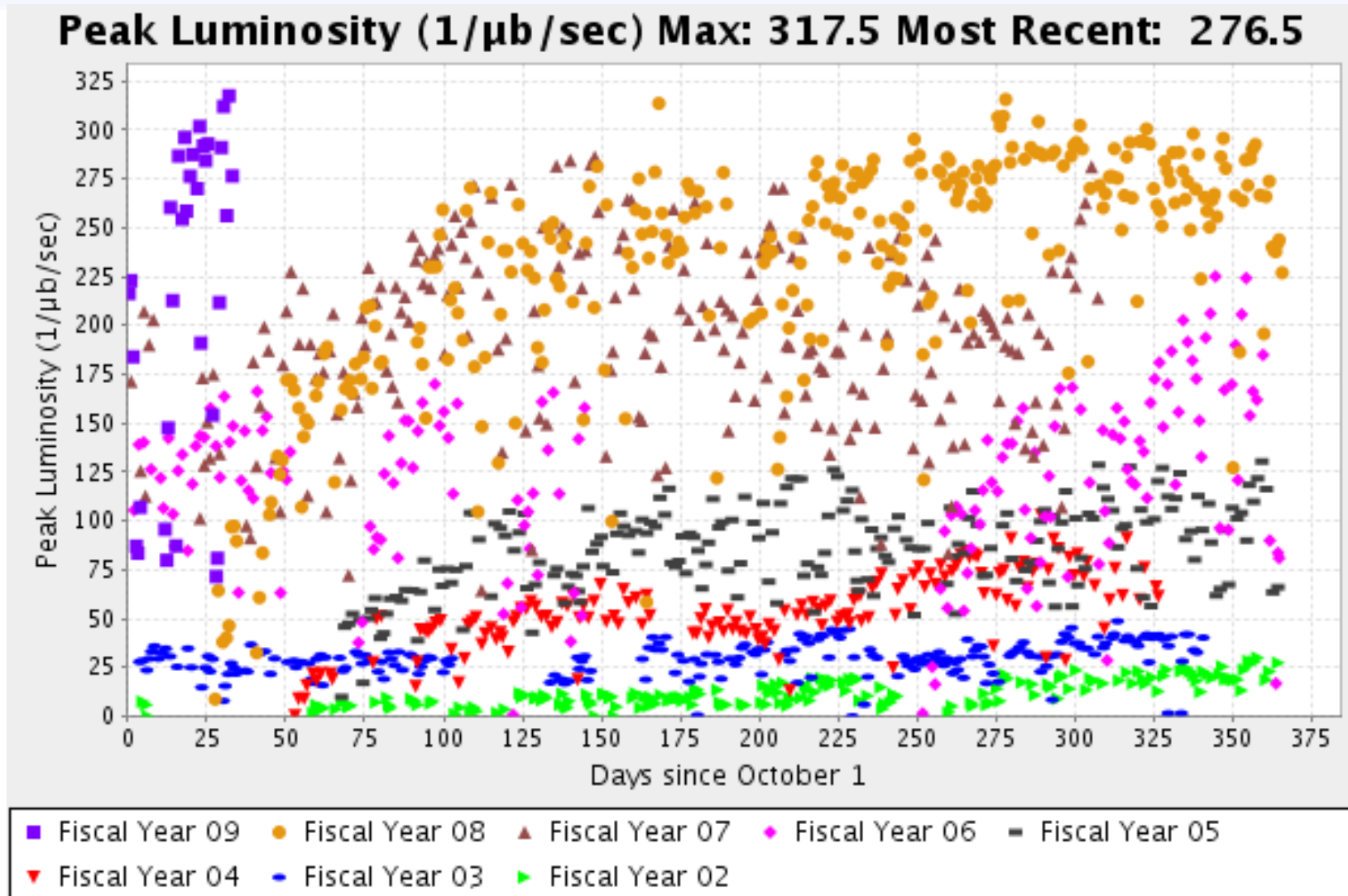
- **Strong motivation to continue running in 2010**
- **Could surpass current predictions for integrated luminosity**
- **Place strong constraints on / Obtain evidence for SM Higgs**
- **Improve top and W mass measurements**
- **Continue investigation of B_s system**
- **Much room for improvement in channels where current analyses use only 1-2 fb⁻¹ (reach 8 fb⁻¹/experiment)**
- **More personnel available in both Collaborations than foreseen**

Backup Slides

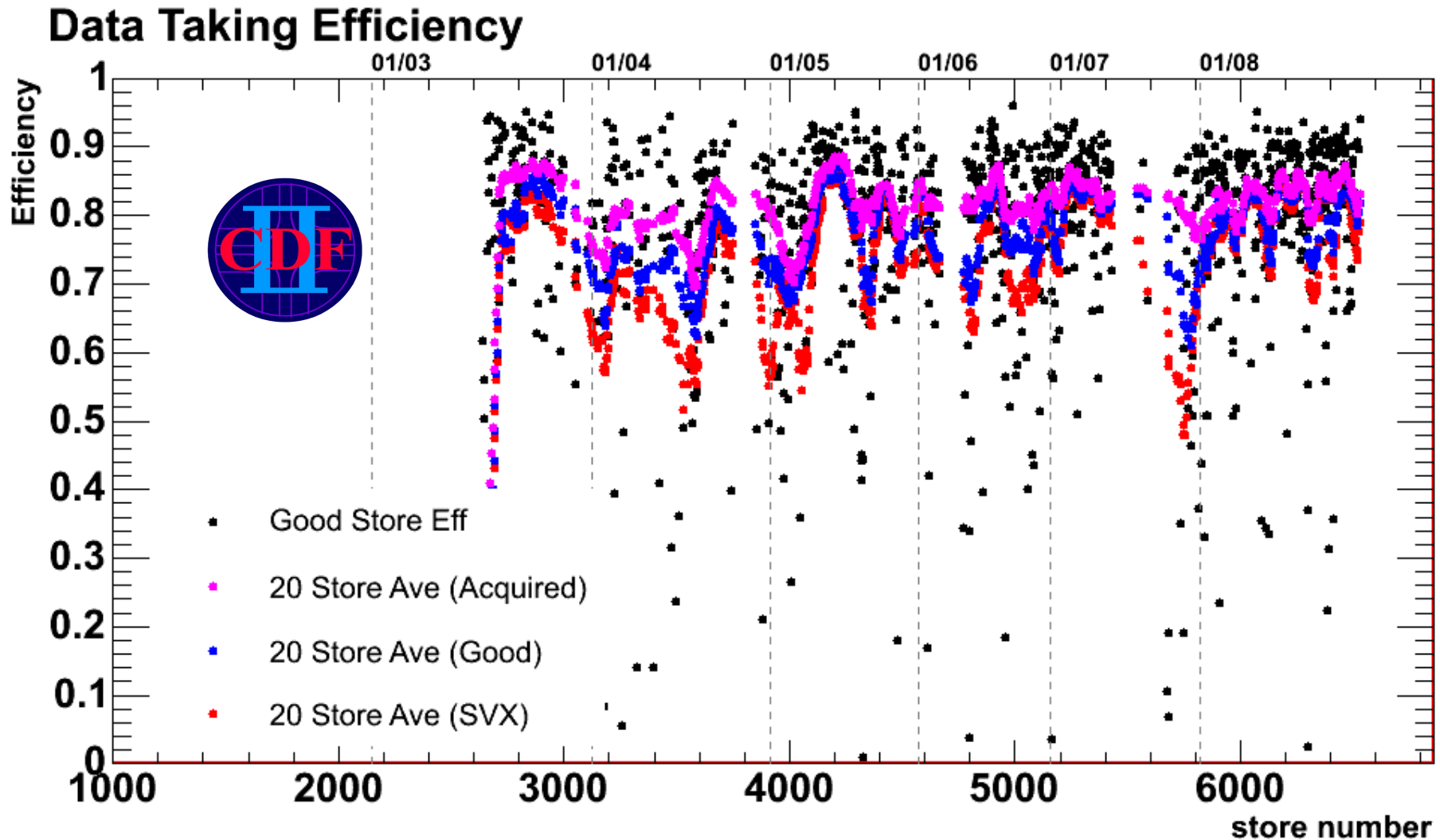
Backup Transparencies



Backup Transparencies



Backup Transparencies

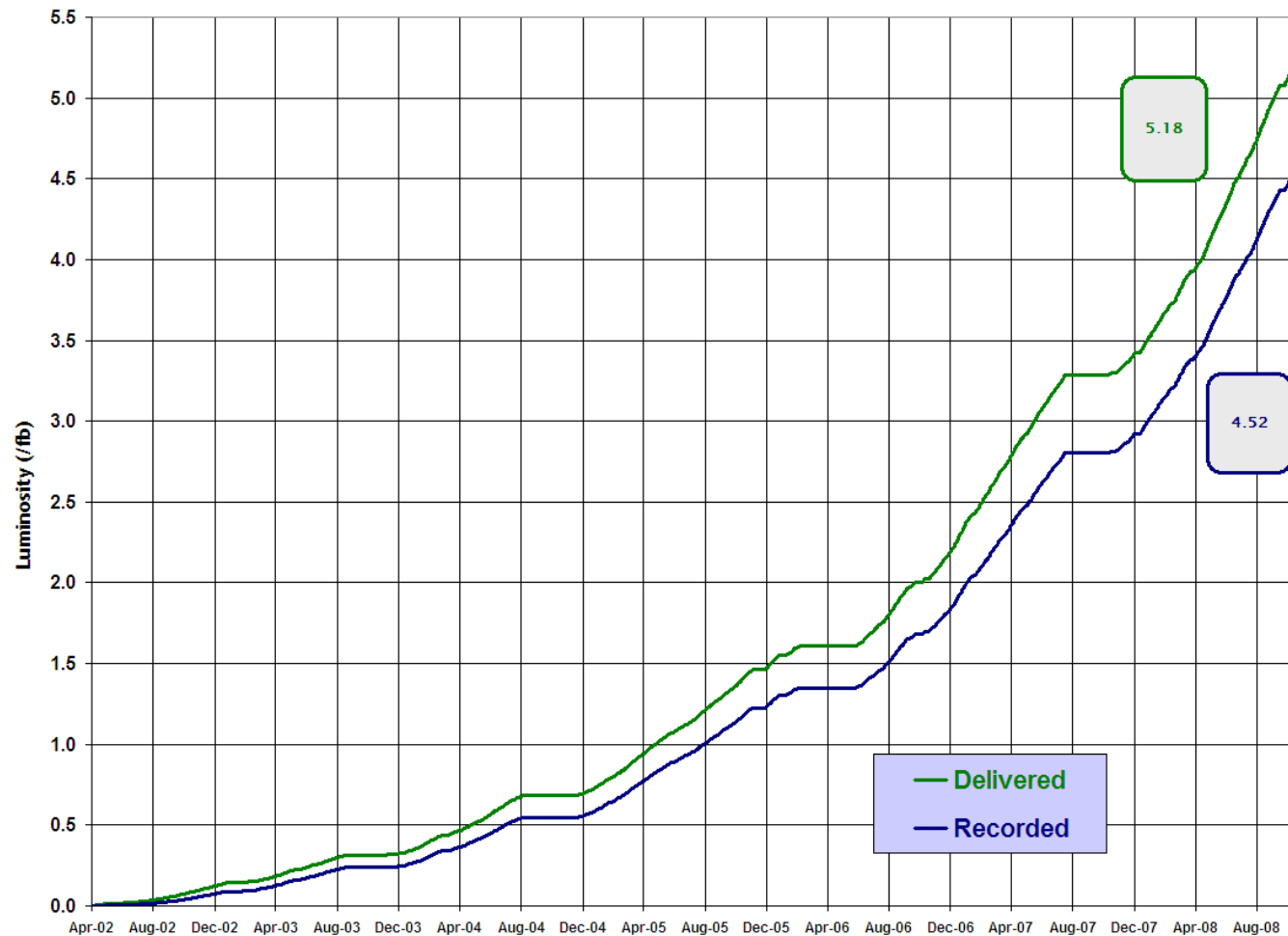


Backup Transparencies



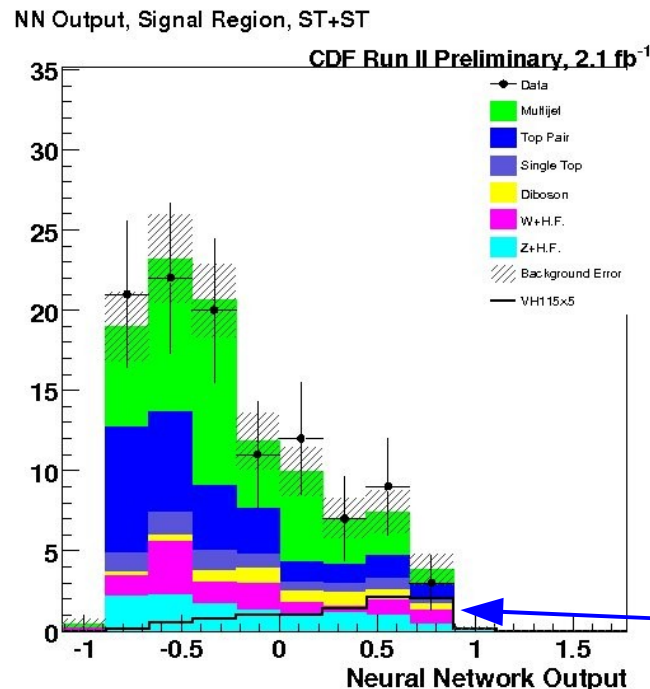
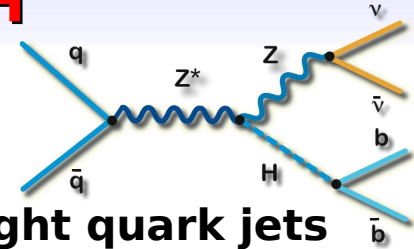
Run II Integrated Luminosity

19 April 2002 - 26 October 2008



Higgs Searches (Low m_H)

- $ZH \rightarrow \nu\nu bb$, $WH \rightarrow l\nu bb$ (l not detected)
- **Signature: MET and b jets**
 - ♦ Primary backgrounds: QCD b jets and mistagged light quark jets
 - ♦ Key issue: Building a model of the QCD background
 - ♦ Shape from 0 and 1 b tagged data samples with tag and mistag rates applied



Innovations:

CDF/DØ : Use of track missing p_T to define control regions and suppress backgrounds

CDF: Uses of H1 Jet Algorithm combining tracking and calorimeter information
3 jet events including $W \rightarrow \tau\nu$ acceptance

DØ also performs a dedicated $W \rightarrow \tau\nu$

Results at $m_H = 115 \text{ GeV}$: 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Limit (σ/SM)	
			Exp.	Obs.
CDF NN	2.1	7.3	6.3	7.8
DØ	2.1	3.7	8.4	7.9

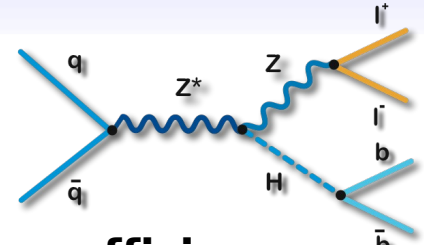
Higgs Searches (Low m_H)

- $ZH \rightarrow llbb$

- Signature: two leptons and two b jets

- Primary background: Z + b jets

- Key issue: Maximize lepton acceptance and b tagging efficiency

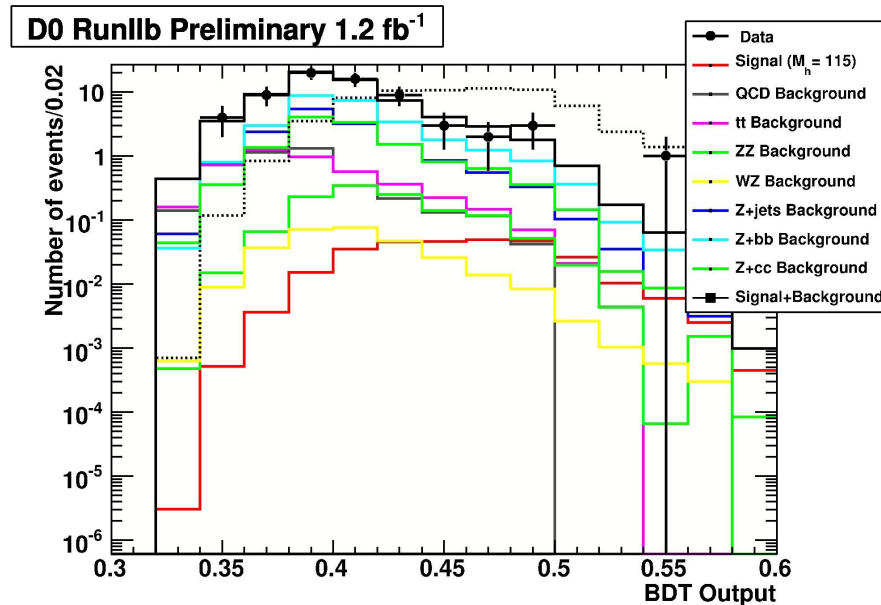


Innovations: CDF/DØ: Extensive use of loose b tagging

CDF: Use of isolated tracks and calorimeter only electrons

MET used to correct jet energies, New ME analysis

DØ : Multiple advanced discriminates, NN and BDT



Results at $m_H = 115 \text{ GeV}$: 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Limit (σ/SM)	
			Exp.	Obs.
CDF NN	2.4	1.8	11.8	11.6
CDF ME(120)	2.0	1.4	15.2	11.8
DØ	2.3	2.0	12.3	11.0